Deep Space Power 2018

Overview of Deep Space Power System Challenges

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Outline

- Deep Space Power System Challenges
- Mission Design Approach
- Planetary Protection
- Mars Sample Return Challenges
- Ocean World Challenges
- Solar Electric Propulsion (SEP) Mission Challenges
- Power Source Options and Performance
- Power Control Architecture and Power Electronics Technology
- Summary
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Deep Space Power System Challenges

- **Power System Trade Space**
  - Power Source Options (RPS, Solar, Fission)
  - Energy Storage (Primary, Secondary, Thermal Batteries)
  - Power Electronics (Power Control, Switching Technology)
- **Science Targets**
  - Potential Mars Sample Return (MSR) (1.6 AU)
  - Ocean Worlds (1AU to 39.5 AU)
  - Asteroids and Dwarf Planets (3 AU)
- **Type of spacecraft/vehicle**
  - Rover (MSL, M2020, MSR)
  - Lander (Europa Lander Mission Concept)
  - Orbiter (Europa Clipper)
  - Solar Electric Propulsion (DAWN)
- **Planetary Protection (M2020, MSR and Europa Lander)**

Power System Challenges are driven by the Science Target

Mission Design Approach

- Power system drivers
  - Duration of mission affects the RPS option (2% to 5% degradation per year)
  - Solar Array performance is dominated by solar range, thermal design and radiation
  - Energy Storage is driven by environment, mission duration and planetary protection
- Launch vehicle
  - Volume of the shroud to fit the stowed solar array
  - Doors in the shroud for RPS installation
  - Battery Safety (small cell protection to thermal run away)
- Trajectory
  - Direct vs. Gravity Assist (can save 4 years duration and inner solar system stress on the solar arrays)
  - Can the tour avoid the radiation? (e.g. Juno, Europa Clipper) (can save up to 20% of the power)
  - Solar range over the entire mission including science tour
  - Avoid eclipses (directly affects solar array temperature and sizes the battery)
  - Landers, Rovers and Sample Returns will determine the environment and planetary protection

The mission design greatly impacts the power system architecture.

Planetary Protection

Planetary Protection Mission Category Definitions

Types of Planetary Bodies	Mission Type[1]	Mission Category[2]
Bodies "not of direct interest for understanding the process of chemical evolution or the origin of life."	Any	I
Bodies of "significant interest relative to the process of chemical evolution and the origin of life, but where there is only a remote chance that contamination carried by a spacecraft could compromise future investigations."	Any	II & II*
Bodies of significant interest to the process of "chemical evolution and/or the origin of life", and where "scientific opinion provides a significant chance that contamination could compromise future investigations."	Flyby, Orbiter	III
	Lander, Probe	IV[3]
Earth-return missions from bodies "deemed by scientific opinion to have no indigenous life forms."	unrestricted Earth-Return	V (unrestricted)
Earth-return missions from bodies deemed by scientific opinion to be of significant interest to the process of chemical evolution and/or the origin of life.	restricted Earth-Return	V (restricted)

[1]If gravity assist is utilized during a flyby, constraints for the planetary body with the highest degree of protection may be required.
[2]For missions that target or encounter multiple planets, more than one PP category may be specified.
[3]Category IV missions for Mars are subdivided into IVa, IVb, and IVc.

Planetary Targets for all Mission Categories

Planetary Targets/Locations	Mission Type	Mission Category
Undifferentiated, metamorphosed asteroids; Io; others TBD.	Flyby, Orbiter, Lander	I
Venus; Earth's Moon; Comets; non-Category I Asteroids; Jupiter; Jovian Satellites (except Io and Europa); Saturn; Saturnian Satellites (except Titan and Enceladus); Uranus; Uranian Satellites; Neptune; Neptunian Satellites (except Triton); Kuiper-Belt Objects (< 1/2 the size of Pluto); others TBD.	Flyby, Orbiter, Lander	II
Icy satellites, where there is a remote potential for contamination of the liquid-water environments, such as Ganymede (Jupiter); Titan (Saturn); Triton, Pluto and Charon (Neptune); others TBD.	Flyby, Orbiter, Lander	II*
Mars; Europa; Enceladus; others TBD (Categories IVa-c are for Mars).	Flyby, Orbiter	III
	Lander, Probe	IV(a-c)
Venus, Moon; others TBD: "unrestricted Earth return"	unrestricted Earth-Return	V (unrestricted)
Mars; Europa; Enceladus; others TBD: "restricted Earth return"	restricted Earth-Return	V (restricted)

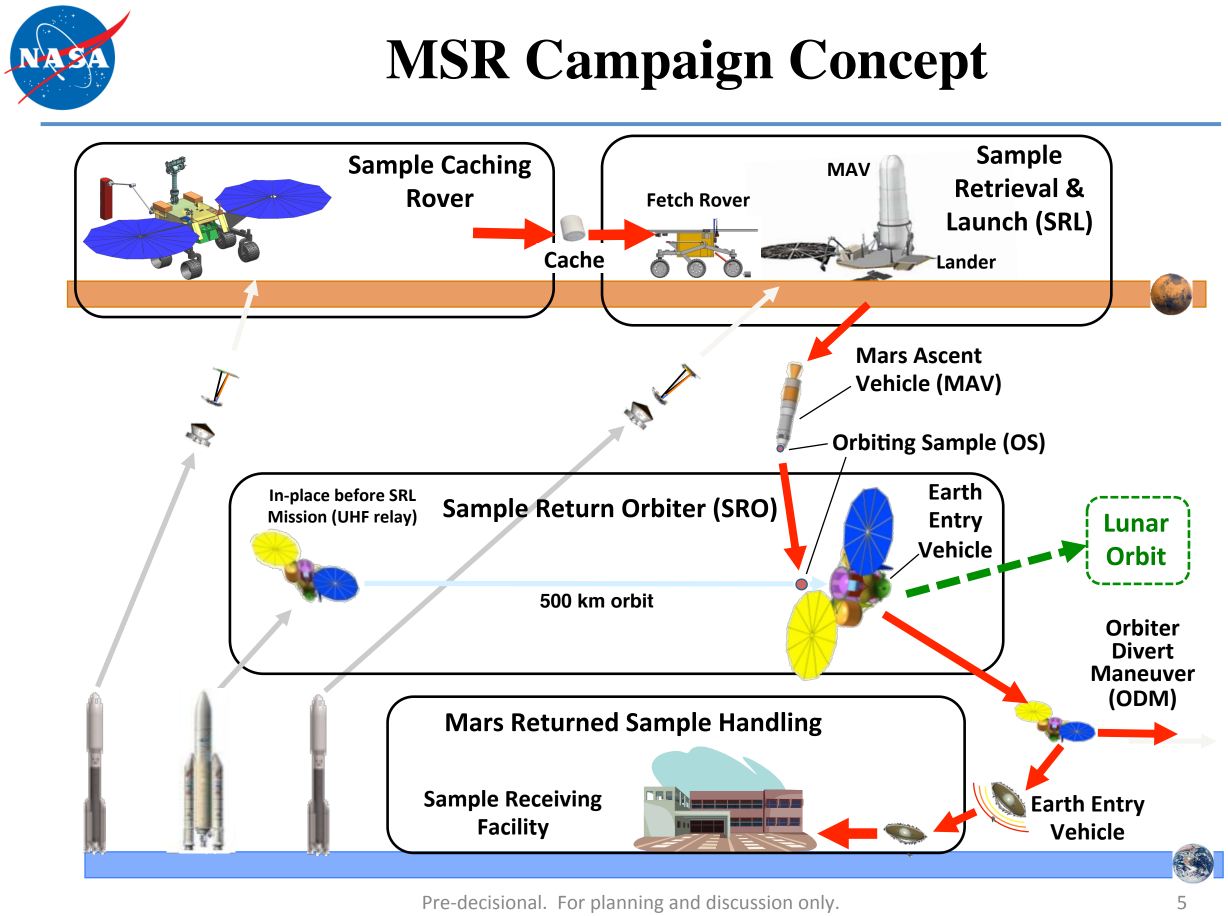
Category IV Subdivisions for Mars (IVa-c)

Types of Mars Missions	Mission Type	Mission Category
Lander systems not carrying instruments for the investigations of extant Mars Life.	Lander, Probe	IVa
Lander systems designed to investigate extant Martian Life.	Lander, Probe	IVb
Missions investigating Martian Special Regions, even if they do not include life detection experiments. Martian Special Regions include those within which terrestrial organisms are likely to replicate and those potentially harboring extant Martian Life.	Lander, Probe	IVc

Credit: https://planetaryprotection.nasa.gov/categories

- Requirements are based on the science target
- Types of mission will determine the category
- Electronics get Dry Heat Microbial Reduction (DHMR)
- Batteries get radiation
- Difficult to handle large solar arrays
- RPS has its own unique challenges

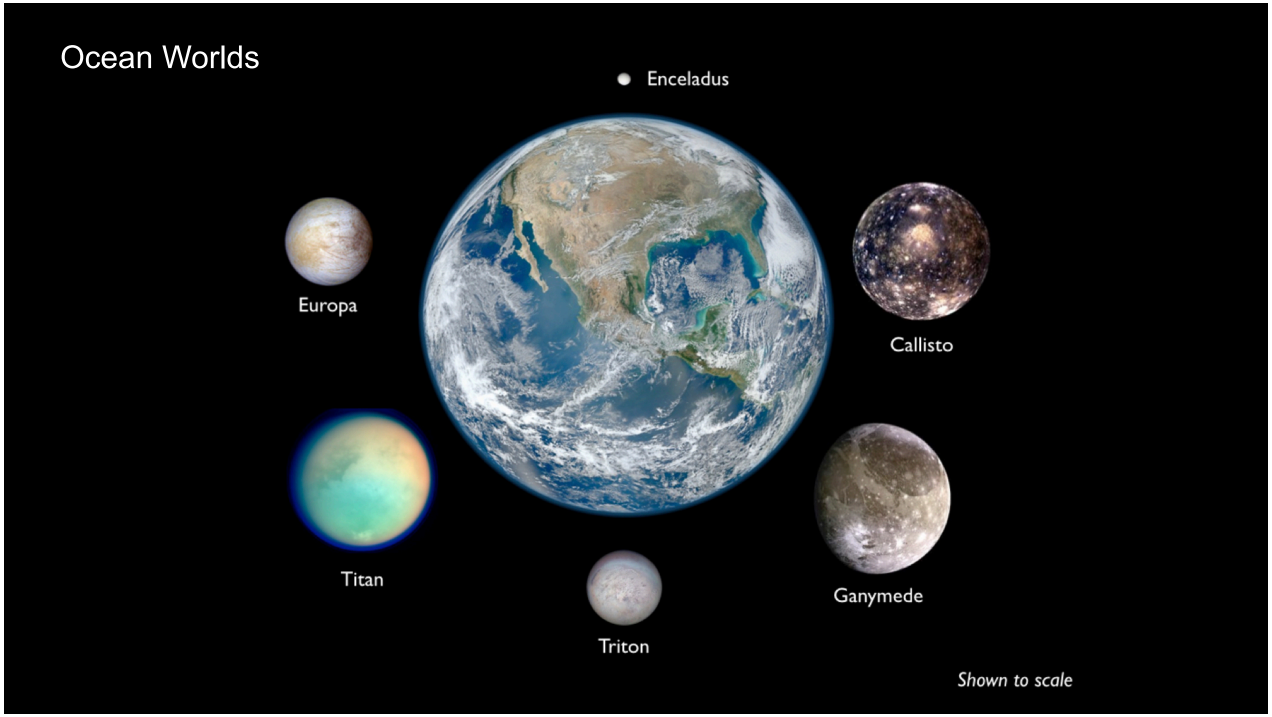
Potential Mars Sample Return



Credit: Bob Gershman, "Sample Contain Technology for Mars Sample Return" 2015

- Large complex systems
- Mission concepts affect the power system approach
- Leverage common electronics across the different platforms
- Power source could vary across platforms
- Energy storage would vary across the different platforms
- Sample handling and "Break the Chain" can drive the electronics design

Ocean World Challenges

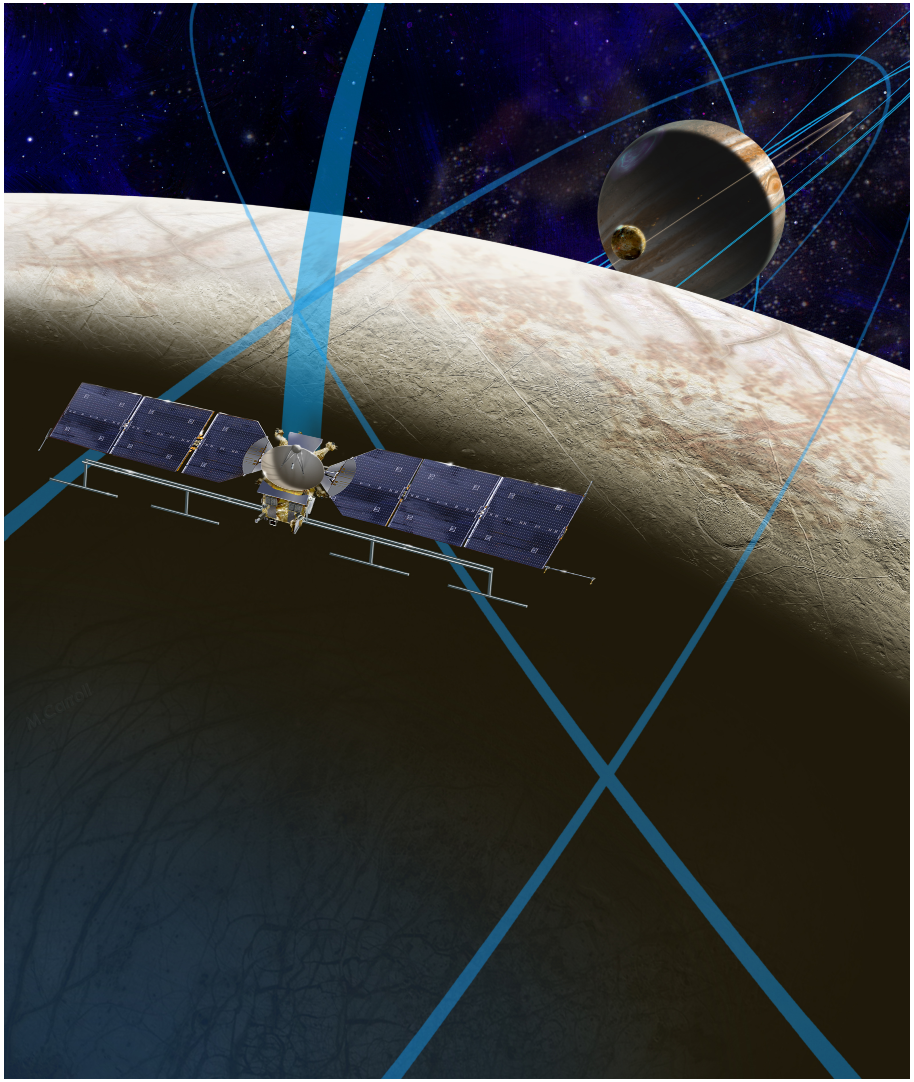


Credit: Kevin Hand, Europa Lander Science Definition Team 2018, europ.nasa.gov

- Solar Range from 1A to 39 AU
- Planetary Protection to protect the surface and oceans
- Extreme Environment
  - Radiation
  - Temperature
- Type of mission
  - Flybys, orbiters and landers
- Science Instruments
  - Radars
  - Landers
  - Melt probes
  - Submarines

Pre decisional: for information and discussion purposes only

Europa Clipper



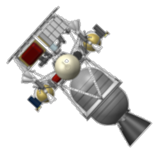
Credit: NASA, JPL Caltech

- Mission Concept Enabled Solar Power
  - Flyby concept reduced the radiation degradation
  - Large Secondary Battery enables higher power science instruments during flyby
- Solar Array
  - Large solar array to deliver end of mission power
  - Radiation degradation is controlled by the number of flybys
  - Close proximity of science instrument is impacting array design
- Energy Storage
  - Li-Ion 18650 cell, ABSL battery
  - Radiation used for Planetary Protection

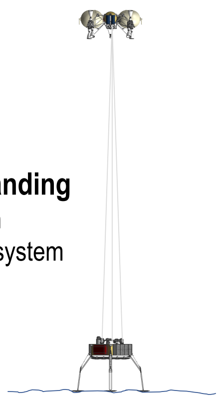
Europa Lander Concept

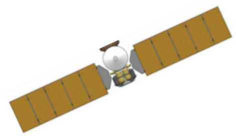
Europa Lander Mission Concept

Cruise/Jovian Tour
- Jupiter orbit insertion Apr 2030
- Earliest landing on Europa: Dec 2031

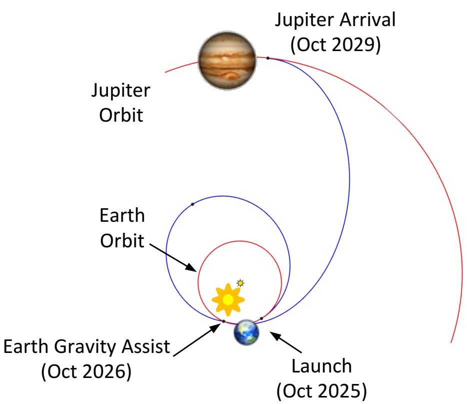


Deorbit, Decent, Landing
- Guided deorbit burn
- Sky Crane landing system
- 100-m accuracy

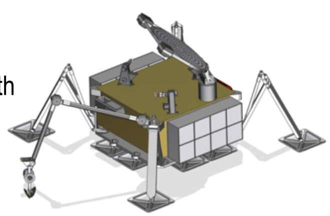




Carrier Relay Orbit
- 24 hour period
- >10 hours continuous coverage per orbit
- 2.0 Mrad radiation exposure



Surface Mission
- 20+ days
- 42.5 kg payload allocation
- 5 samples, 7 cc each, >=10 cm depth
- Relay comm through Carrier or Clipper (backup)
- 3–4 Gbit data return
- 45 kWh battery
- 1.5 Mrad radiation exposure



Launch
- SLS Block 1B
- Oct. 2025 earliest

Pre-Decisional Information – For Planning and Discussion Purposes Only

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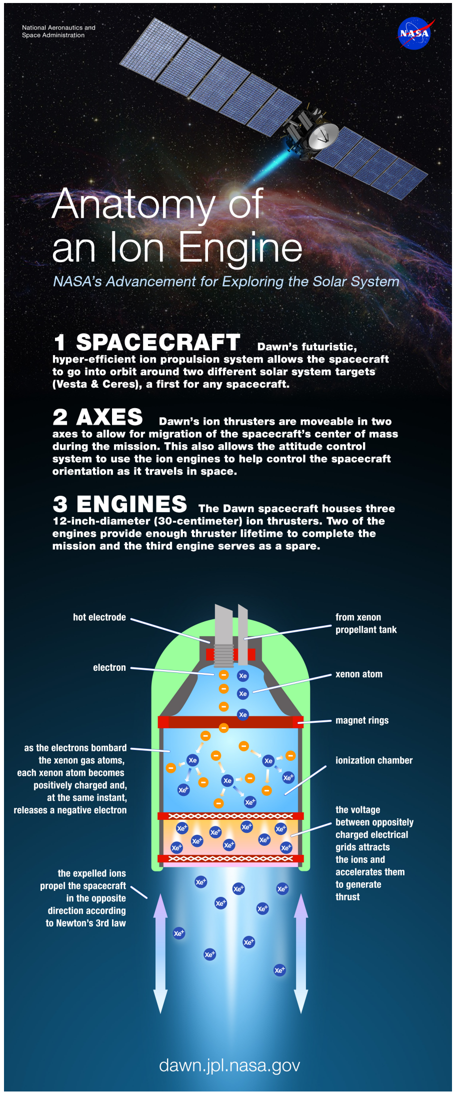
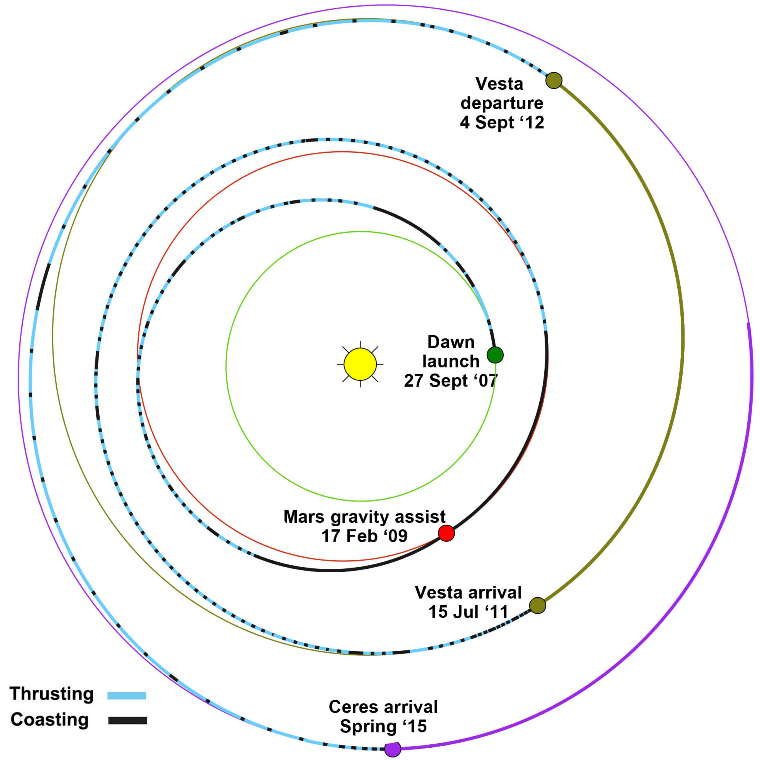
Credit: Kevin Hand, Europa Lander Science Definition Team 2018, europa.nasa.gov

SEP Missions





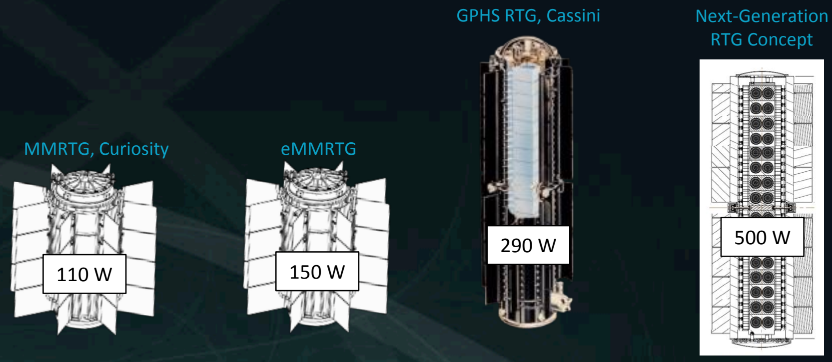
Credit: dawn.jpl.nasa.gov

- Solar Range
  - Optimizing at the target
  - Solar voltage varies though out cruise
- Higher Voltage Solar Array
  - PPUs run at higher voltage
  - EP uses most of the power
- Power Control Architecture
  - Optimized for PPU efficiency
  - Avionics Power Bus has energy storage
  - Peak Power Tracking vs. Ground in the loop array management

Pre decisional: for information and discussion purposes only

RPS Options

Next-Generation RTGs for NASA
Concepts



Power, launch, W	110	150	290 (880)	500
Power, end of life, W	55	91	213 (640)	362
Degradation rate, av	4.8%	2.5%	1.9%	1.9%
# GPHSs	8	8	18	16
Length, m	0.69	0.69	1.14	1.04
Mass, kg	45	44	57	62

Pre-Decisional for Discussion Only 31

- Excellent Deep Space Power Source
  - Mission Duration Degradation
  - Not impacted by solar range
- Higher cost
- Launch approval
- Long Lead Time
- Provides useable thermal waste energy that reduces the load of electrical heaters
- Energy Storage
  - Is optional with RPS
  - Greatly enhances capability (MSL)

Credit: Dave Woerner, RPS Program Office, rps.nasa.gov, Next Generation RTG Presentation, 2017

Solar Array Performance

- The solar array performance can be initially determined by manufacturer's cell specification
- Eventually cell testing for the end of mission environment needs to be used for solar array design
  - Includes Low intensity Low Temperature (LILT) impact
  - Screening criteria can be determined from cell test data
- The complete mission design tour and solar range needs to be considered in the design of the array
  - Solar range and temperature will impact power control design and desired operating point
- The array design needs to be optimized for peak performance at the critical points in the mission which may not be the end of mission
- A large array will have a significant impact on the system

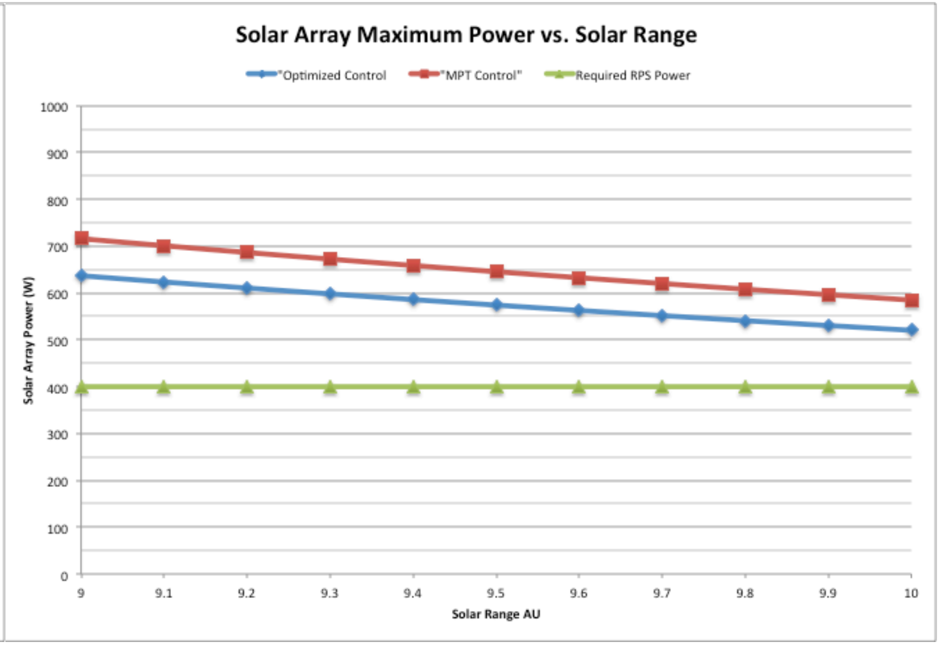
Consideration of Solar Array for deep space missions is an end-to-end system level trade

Thermal Design Approach

- Needs to be considered early in trade space
- It can make the difference between RPS and Solar
- Defines the minimum power required for the spacecraft
- The waste heat of the components needs to be used
- The temperature of the propellant can set the minimum power requirements (can affect the minimum power by 100W)
- Thermal design needs to consider fluid loops and heat pipes to reduce the electrical power requirements (can save 200W)
- The temperature range of the solar array affects the operating point and power control architecture

The thermal design could swing the trade for power source selection.

RPS power vs. Solar Power (10 AU)



The required RPS EOM power of 400 W at 10 AU and high radiation could translate to a between 35 and 40 kW at 1 AU solar array.

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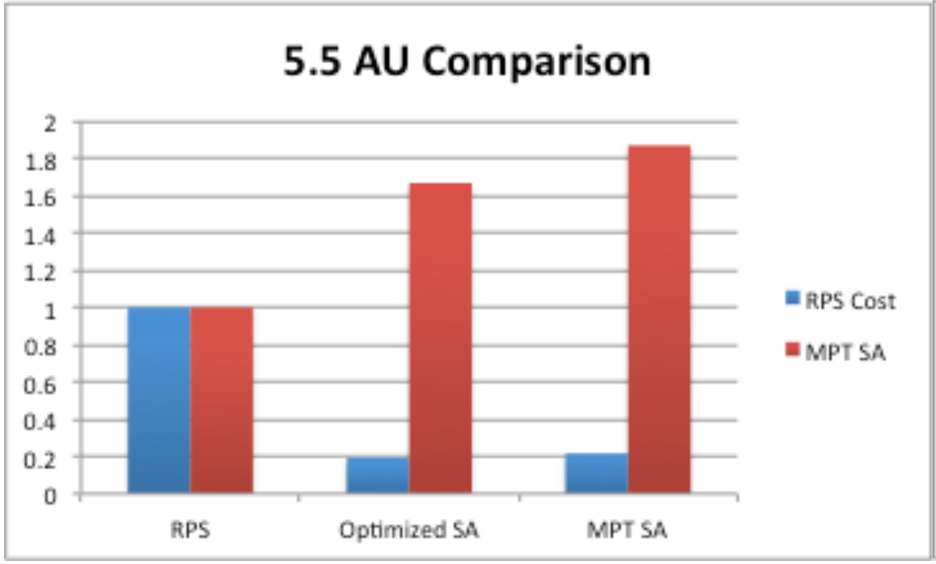
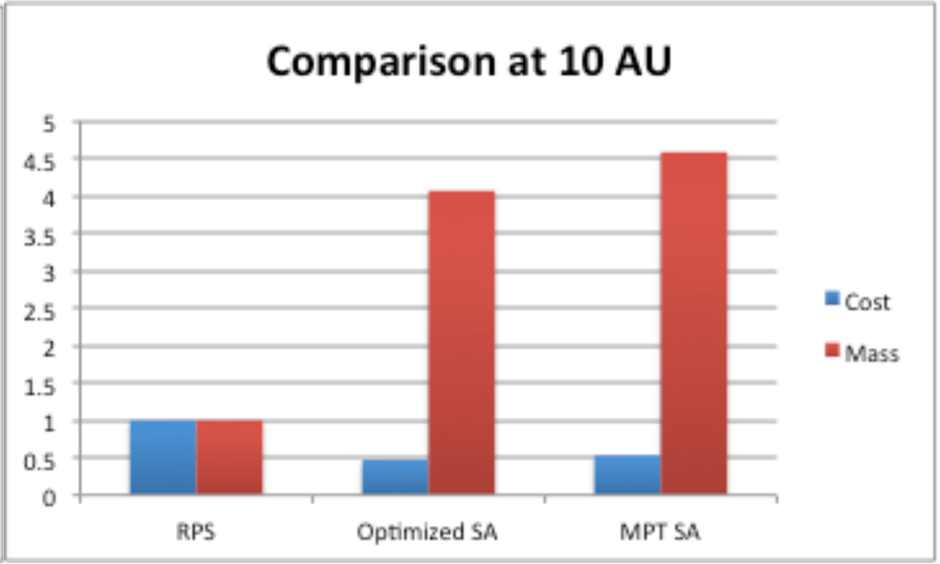
Overall System Performance Evaluation





Cost would be significantly lower (12%) for solar at 5.5 AU with a significant mass impact (67%).
Cost would be still lower for 10 AU (50%) but mass would be a factor of 4 greater.

Power Electronics Technology

- **Power Control architecture can improve the amount of power available from the array through out the different mission phases**
  - **Maximum Power Tracking**
  - **Ground in the loop solar array collapse prevention (Dawn, Clipper)**
  - **Direct energy transfer with variable string lengths (Juno)**
- **GaN power switching technology**
  - **Can improve efficiency of switching regulators by approximately 5%**
  - **Can switch a high voltage to support SEP missions**
  - **Can operate in a high radiation extreme temperature environment**

The combination of power control architecture with new switching technology can improve the overall performance of Solar Arrays and Batteries for deep space systems.

Summary

- Deep space power system challenges are driven by the science target.
- The mission design can greatly influence the power source selection and enable solar power for many deep space missions.
- Planetary Protection Requirements are very challenging for Large Solar Arrays, RPS and Batteries
- The solar array design consideration is an end-to-end system level assessment
- The thermal design could swing the trade for the power source selection.
- New technology in power electronics and power control architecture can improve solar performance through out the mission
- Up to about 10AU, deep space power systems are trading mass for cost and schedule between soar arrays and RPSs

The improvement in solar array performance and RPS performance is not only making deep space missions viable but providing more options at the system level to improve science return.

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